FERMILAB MAIN RING ION PROFILE MONITOR SYSTEM

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Abstract

An Ion Profile Monitor System is now in operation in the Fermilab Main Ring. This system captures up to 64K samples of both horizontal and vertical profiles in Main Ring at a turn by turn sample rate. The hardware and software of the system is described. Some early results are presented.

1 INTRODUCTION

Three Ion Profile Monitor (IPM) systems have been developed and installed in the Fermilab Main Ring. These systems incorporate many improvements but are based on the design installed in the Booster[1]. The monitors have been improved in mechanical design for better vacuum, ease of installation and maintenance, and utilize an increased clearing field of up to 30 kVolts to accommodate the increased intensity and beam energy of the Main Ring.

Operation of the monitor relies on residual gas molecules in the vacuum being ionized by the charged particle beam. The ions are accelerated toward a microchannel plate (MCP) by the applied clearing field. The MCP provides many electrons for each incident ion which are collected on anode strips running longitudinally with the proton beam. The charge on each strip is amplified, digitized, and saved in memory to produce single pass profiles.

1.1 Location

The horizontal monitors are located at A17 and F48; F25 is the vertical profile monitor.

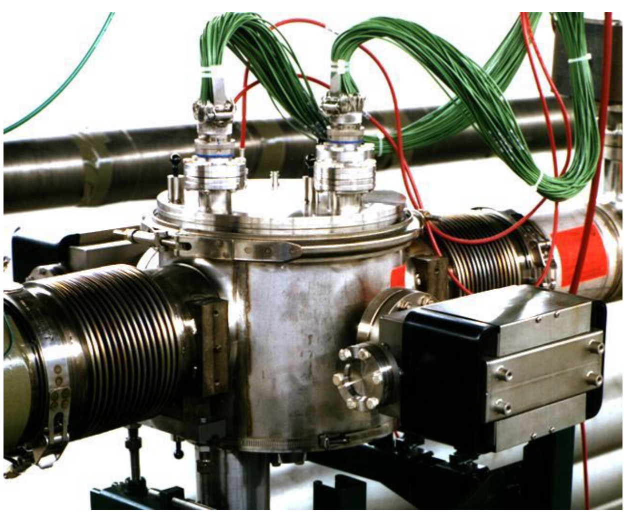

Figure 1. F48 Horizontal tunnel installation.

1.2 Components

The tunnel portion of the system consists of the vacuum housing containing a high voltage clearing field and field shaping components, MCP, and an anode strip circuit board. The circuit board contains a series of 120 signal anode strips on 0.5 mm centers, located below the plate, to collect the resulting electron charge.

Upstairs the raw signals are fed into an amplifier assembly and then to 12 bit, 4 channel Omnibyte™ Comet 2 MS/s VME digitizers. A total of 64 channels are digitized at a turn by turn sample rate to collect 64 k profiles. The data is read from the digitizers and analyzed by a MacIntosh™ 9500/150 using National Instruments™ PCI-MXI interface and LabVIEW® Software.

The instruments are remotely located in service buildings with no keyboard or monitor. Control of the measurement and the resulting data are made available via ethernet to the Fermilab ACNET Control System or accessed through the use of commercial communication packages such as Farallon™ Timbuktu.

The high voltage supplies for both the clearing field and MCP bias are controlled via PCI-GPIB interfaces. Immediately following a measurement, MCP voltage is turned off to conserve the lifetime of the plate.

2 PROFILE SIGNAL GENERATION

The quality of the image depends on many variables: the number of residual gas molecules, beam intensity, clearing field, and MCP gain. Noise pickup in the long signal cables contributes significant degradation to the signal to noise ratio.

2.1 Residual Gas

The Main Ring vacuum was analyzed to determine the nature of residual molecules in the vacuum pipe. The principal gasses found, (their associated atomic mass units), and partial pressure in Torr, were Hydrogen (2) $2.2*10^{-7}$ Torr, water (18) $1.8*10^{-7}$, water (17) at $5.1*10^{-8}$, Nitrogen, CO, and Ethane (28) at $4.5*10^{-8}$, Carbon Dioxide (44) at $1.5*10^{-8}$, and Oxygen (32) at $7.3*10^{-9}$.

2.2 Ion Production for IPM

Sauli [2] gives the ion production for minimum ionizing particles in O_2 and CO_2 as 22 and 34 primary ions/cm of gas at STP (1 atm, and 293° K respectively). If we take the average of these two gases (28 ions/cm) as

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a starting point, we can calculate the ion production (IP) at 10^{-8} Torr by:

IP = 28 ions/cm (10^{-8} Torr/(760 Torr/atm)) = 3.7 $*10^{-10}$ ions/cm.

This is the ion production of a single relativistic particle in a vacuum of 10^{-8} Torr. If we assume that the particle beam (with N protons or antiprotons) has a circular Gaussian shape, then the number of beam particles in a strip *dx* is

$$N(x)dx = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{x}{\sigma})^2} dx$$

For a beam of N= 10^{11}, σ = 2 mm , and a strip at x = 0 with width = 0.5 mm, the number of beam particles is $2.0 * 10^{10}$.

Multiplying the expression for the number of ions by this gives a total ion production of 7.4 ions/cm. If the strip is 10 cm long, we will collect 74 ions in the central part of the profile. This number can be scaled up by beam intensity and vacuum.

For example, a "typical" 2B cycle had a proton intensity (in Main Ring) of 30 $*10^{11}$ p. If the vacuum was 10^{-8} Torr, we would produce 2200 ions on the center strip of the IPM.

If the MCP has a gain of 5k, then the output charge onto the strip is $5 * 10^3 * 2.2 * 10^3 * 1.6 * 10^{-19}$ C/e = 1.8 pC.

3 ELECTRONIC DESIGN

The amplifier was designed with a 100 ohm input impedance which together with the capacitance of 30 meters of cable forms a 300 kHz low pass filter providing sufficient rise time for the 1.6 usec beam length. A current feedback amplifier, an AD844, was chosen for the first stage because of its ability to deal with high frequency noise. The second stage consists of both an OP37 and LH0002 in a single feedback loop configured to take advantage of the OP37 bandwidth and the power driving ability of the LH0002.

3.1 Amplifier Gain And Noise

The amplifiers have an overall voltage gain of 1500 and an input impedance of 100 ohms that together form a transimpedance of 150 kohm. The measured noise levels agree with specifications and correspond to an input current of 23 nA, the input noise of the AD844 amplifier. Sixty-four channels are placed on a single board, and two boards are combined in a single chassis to provide 128 independent channels. Coupling between channels has been measured to be less than -46db.

The high impedance and thin conductive coating of the MCP allows electromagnetic fields generated by the beam to pass through and induce currents directly in the electron collecting anode strips. These signals consist of the bunch frequency and several harmonics, much higher in frequency than the desired signals. This high frequency noise can be rectified in the first amplifier stage producing offsets that change with intensity and bunch length and can be seen with no voltage on the MCP. To combat this problem, the wires inside the detector leading to the strips are shielded, a second order low pass filter is placed in front of the amplifier, and a current feedback amplifier is used. These steps greatly reduce but do not eliminate the problem. Current feedback amplifiers have high bandwidths and fast slew rates which reduce the effect but they have poor temperature stability and drift. However, these errors change slowly and are corrected in software by measuring the offsets without beam.

3.2 Measured Signals and Noise

For $1*10^{12}$ protons, the strip with the largest signal at the amplifier is about 670 nA through the 1.6 μsec batch. Common operating levels of 810 volts provide an unsaturated gain of 3800 indicating about 1800 ions strike the MCP. The signal to noise ratio of the MCP is the square root of this number or 42. The signal to noise ratio of the amplifier is 29. The impedance across the MCP is 10 Mohms and the bias current is 510 nA for each strip. The manufacturer recommends signal currents be less than 10% of the bias current. We have been running well into saturation in an effort to overcome noise picked up in the 30 to 150 meter signal cables between the detectors located in the tunnel and the amplifiers located in the equipment gallery.

Noise induced on the signal cables is currently limiting performance of the system. It consists of short pulses of a volt or less in amplitude having duration of a few μsec. They are locked to the power line frequency and are believed to originate from SCR firing pulses controlling the main bus power supplies. They are separated in time by a few msec making the duty cycle low. Data is collected every turn and about one turn in 100 is corrupted with noise and is unusable. The strips which collect charge from the MCP are electrically open, making the source impedance very high which reduces noise currents. To overcome noise induced in signal cables, it is planned to place the amplifiers in the tunnel closer to the detector.

DATA HANDLING

A measurement is started by specifying the clock event on which to capture data. The MCP voltage is adjusted based on the anticipated intensity for the selected event. The data is captured using a beam synchronous clock system and is digitized once per turn until the entire 64 ksample/channel memory is full. Then 8.5 Mbytes of data is read out of the VME chassis, background and offsets subtracted, display of charge and intensity vs turn, and a multicolor intensity plot (figure 2) is created in 4.5 seconds. The data can then also be displayed as a single profile, or sigma and position plot using a nonlinear fit.

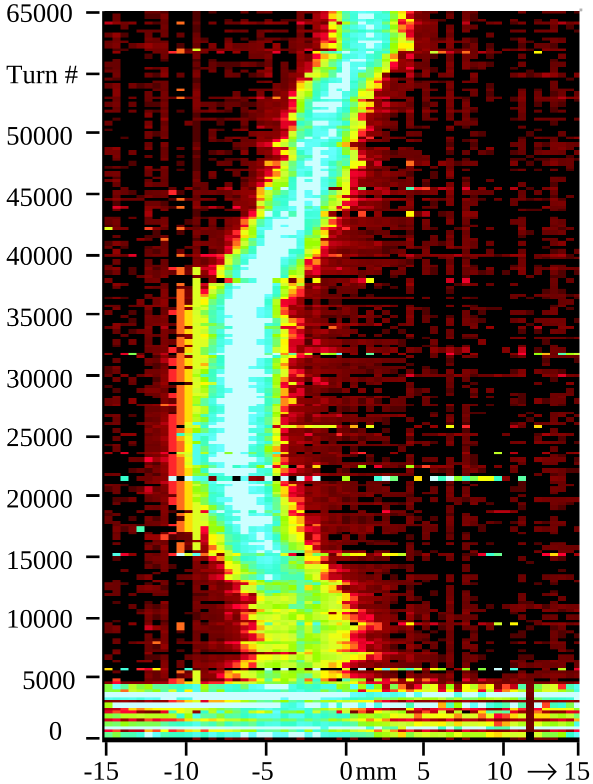

Figure 2. Multicolor Intensity Plot

The data analysis uses an optimized non-linear Levenberg-Marquardt algorithm. The system selects 200 profiles from the range specified, fits the data, and generates a display in 3.2 sec. This particular routine is also used in other instrumentation systems that deal with beam parameters [3].

4 MECHANICAL DESIGN

The mechanical design of the Main Ring Ion Profile Monitor includes several improvements over previous devices: higher clearing field voltage, higher vacuum compatibility, better sensor mounting mechanisms, and precise alignment features. These improvements also contribute to ease of maintenance.

The clearing field assembly is comprised of two 15 cm diameter stainless steel discs spaced 10.2 cm apart by two rectangular ceramic plates. Each ceramic plate is outfitted with five copper bars and six voltage dividing resistors to ensure a uniform clearing field across the gap. The lower potential electrode disc has a 8 x 10 cm rectangular opening in which the MCP is located.

The sensor assembly consists of a rectangular 8 x 10 cm MCP and an electron collecting signal anode strip circuit board. The MCP is delicately held into a precisely machined polystyrene mount by BeCu finger springs. The anode strip board is mounted 3.2 mm below the MCP on two aluminum mounting blocks. The mounting blocks feature small alignment pins which enable replacement of the anode strip board without requiring re-alignment. Signal connections to the board are made via custom designed polystyrene connectors. The connectors are designed to allow easy replacement. Nickel signal wires coated with poly-(amide-imide) insulation are used to bring the anode strip signals out to two commercial hermetic feed through connectors.

Ease of maintenance and precise alignment of internal components are further facilitated by mounting all the internal monitor parts to an easily removable end flange. This end flange has an outer diameter of 32 cm and has piloting pins to ensure proper and repeatable alignment in the monitor's vacuum housing. This allows work to be done on the interior components and then be replaced without requiring re-surveying.

Clearing field high voltage is fed into the vacuum housing through a 30 kV commercial feed through mounted opposite the end flange. A stainless steel disc mounted on a ceramic standoff tube transfers the high voltage to the high potential electrode disc (mounted on the end flange structure) via several BeCu spring fingers.

All internal components of the monitor were tested for vacuum compatibility. Where possible, machinable ceramic material is utilized rather than water absorbent organic materials. However, the anode strip board is constructed from an epoxy-glass laminate (G-10) which is notorious for its outgassing characteristics. Future boards will be made using a Teflon®-glass laminate material which has a much lower outgassing rate.

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REFERENCES

[1] Zagel, J. R., Chen, D., Crisp, J.L., "Fermilab Booster Ion Profile Monitor System Using LabVIEW", 1994 Beam Instrumentation Workshop, AIP Conference Proceedings 333, pp384-390.

[2] Sauli, F., "Principles of Operation of Multiwire Proportional and Drift Chambers", CERN 77-09, 3/5/77

[3] Hahn, A.A., "A Levenberg-Marquardt Least Squares Fit Algorithm Optimized for LabVIEW", Technical Note, 1997.